VOLTA CHEM

Electrification of the Chemical Industry

# Electrosynthesis of lactic acid

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www.voltachem.com

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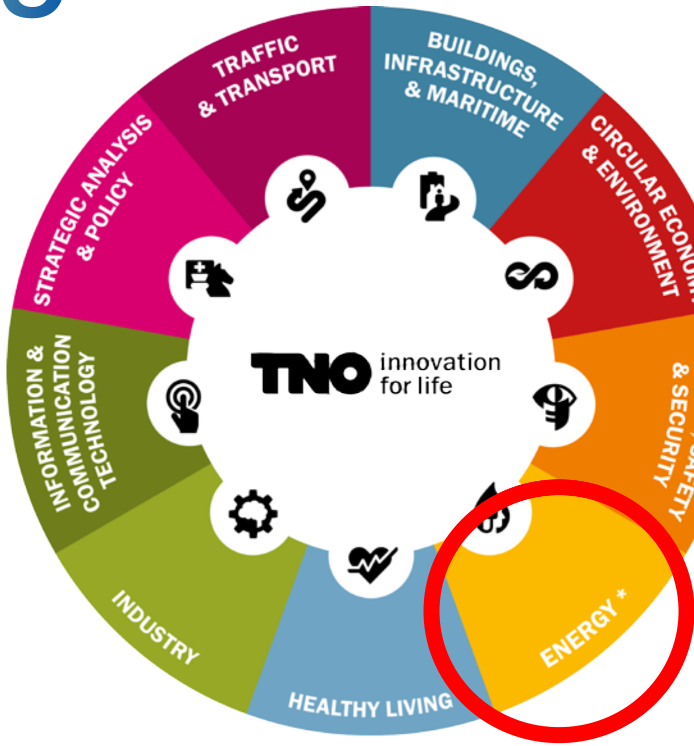
Powered by: TNO innovation for life ECN

# Content

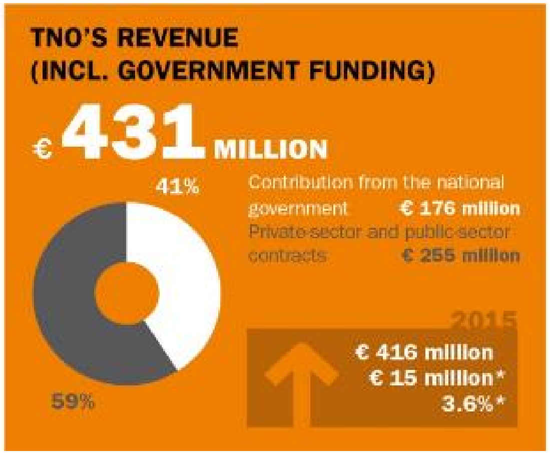
- TNO & VoltaChem
- Background lactic acid
- Technology
- Experiments / results
- Techno-economic evaluation
- Conclusions

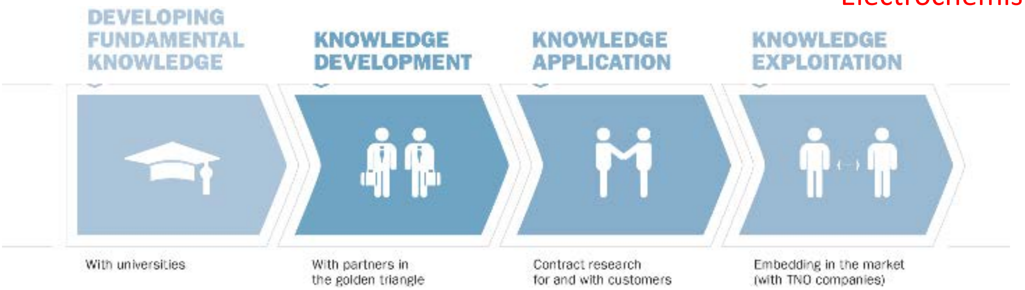
# TNO



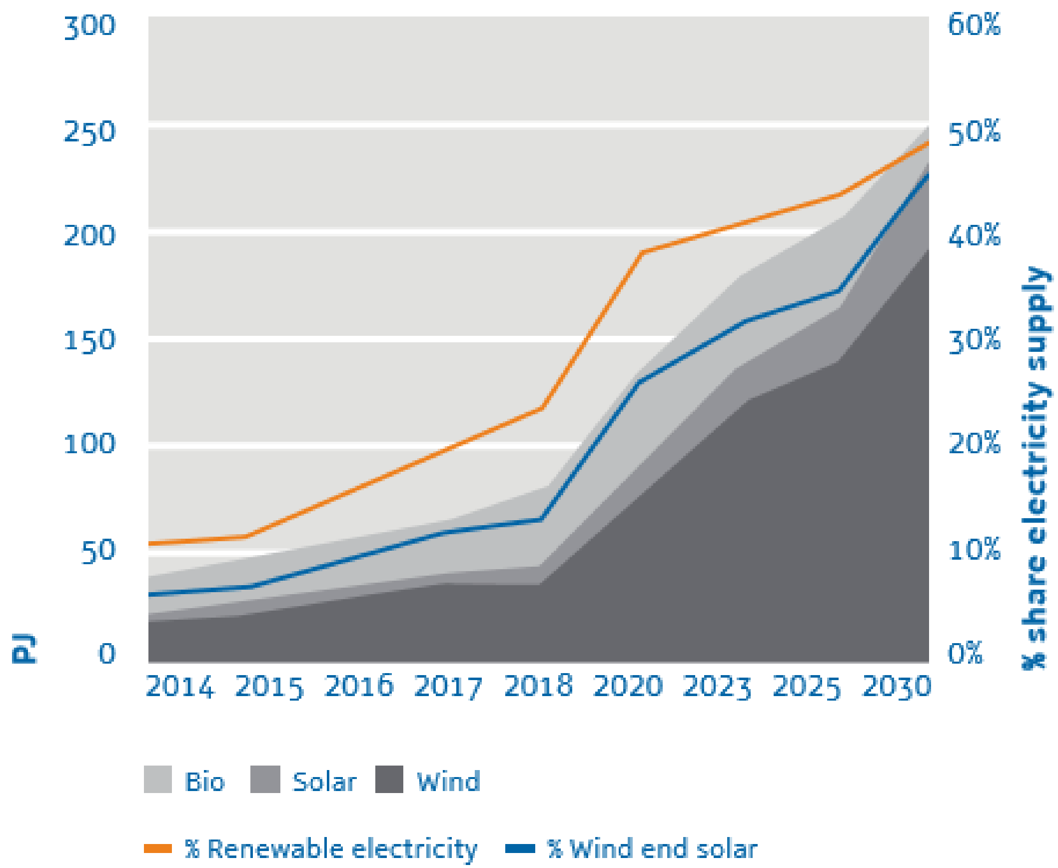

SPES TNO

- Carbon capture and storage
- Renewable gas
- Heat storage
- Hydrogen production/use/integration
- Chemicals from biomass
- Electrochemistry

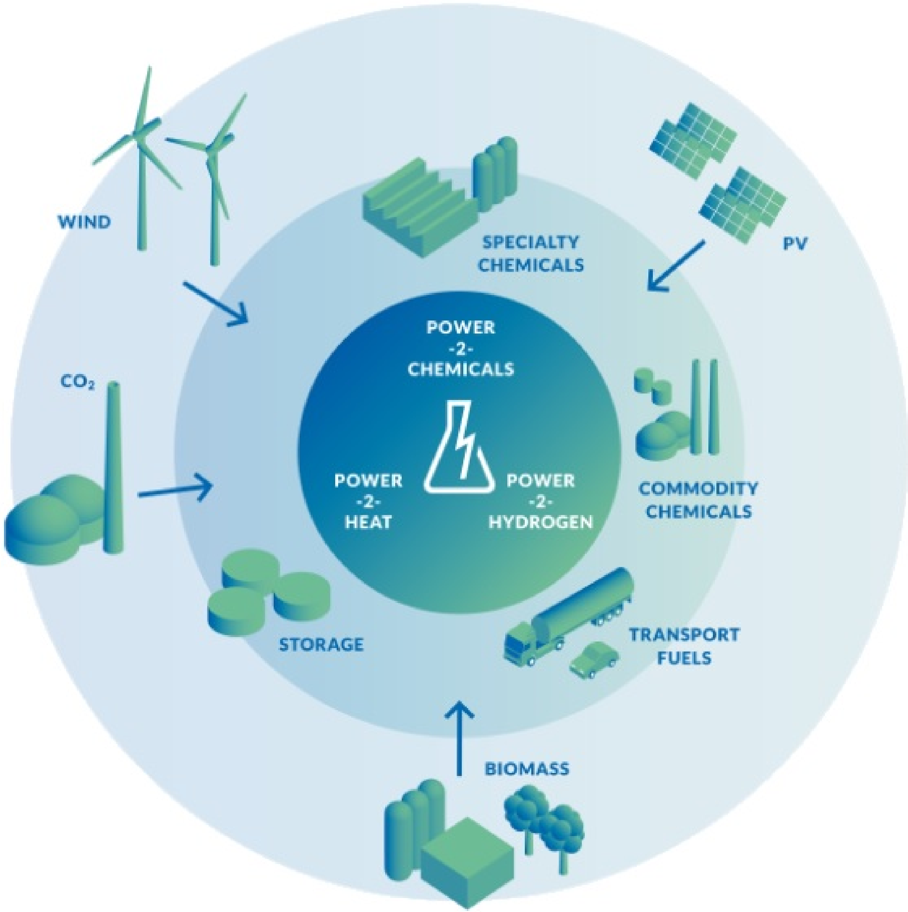




# Renewable electricity



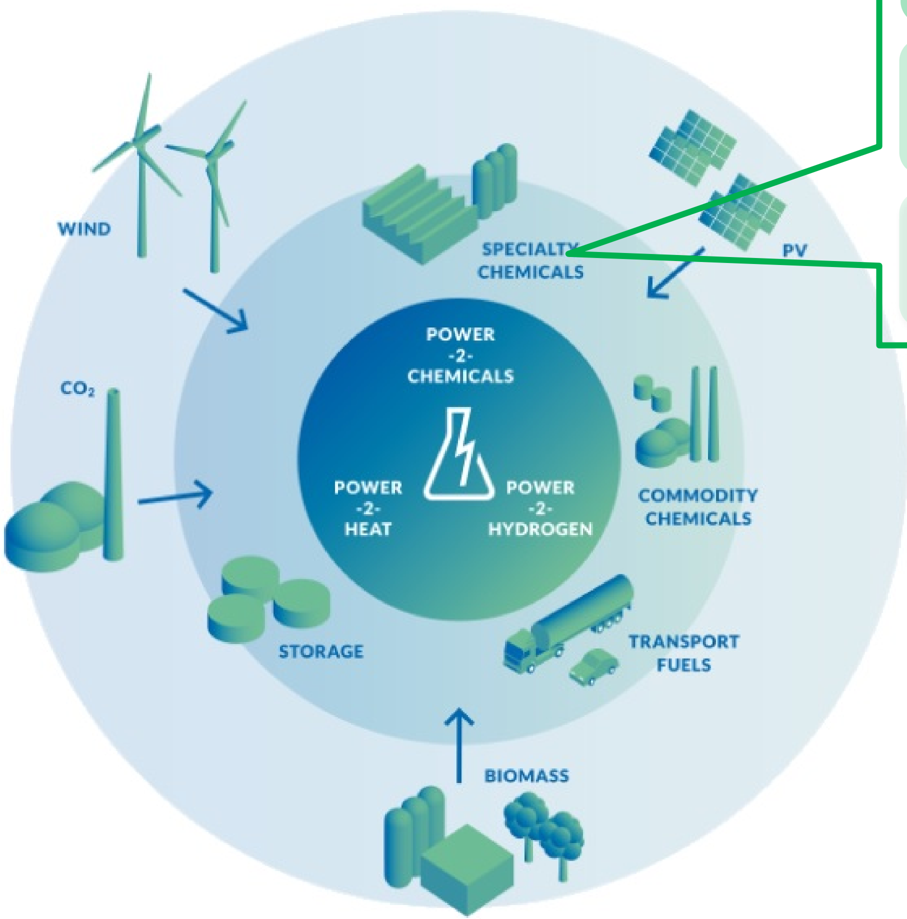

ECCM report: Berenschot study

# VoltaChem




- Public-Private ***Shared Innovation Program*** of ~4 M€ / year, initiated by TNO, ECN and Topsector Chemistry.
- Accelerate innovation and implementation of ***electrification & decarbonization*** in chemicals.
- Initiate and facilitate ***collaborative development*** *of technology and associated business models*.
- Addresses both the *indirect and direct use of electricity* within the chemical industry, involving stakeholders from ***chemicals***, ***energy & equipment supply***.

# VoltaChem




## Power to chemicals

- Electro-organic synthesis
  - Electro-oxidation
    - ✓ Oxidation of furfural
    - ✓ Oxidation of hydroxymethylfuran
    - ✓ Oxidation of alcohols
  - Electro-reduction
    - ✓ Reduction of furfural
    - ✓ Reduction of hydroxymethylfuran
    - ✓ Reductive amination
    - ✓ Reduction of oxygen
- $CO_2$ electro-reduction

# Focus of TNO: upscaling of electrochemical production processes & TEA

# Focus of TNO: upscaling of electrochemical production processes & TEA

Literature study and expert guess

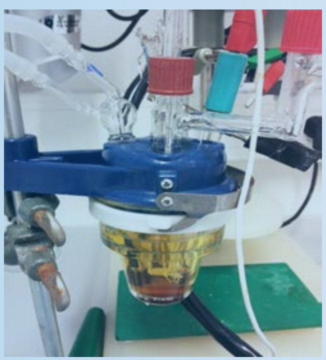
Downstream processing

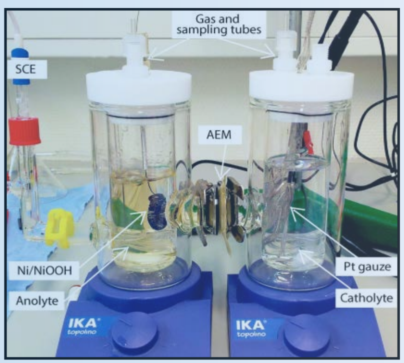
Economical evaluation

Electrochemical systems

**Selection and design of electrochemical systems/system development**

System integration & demonstration





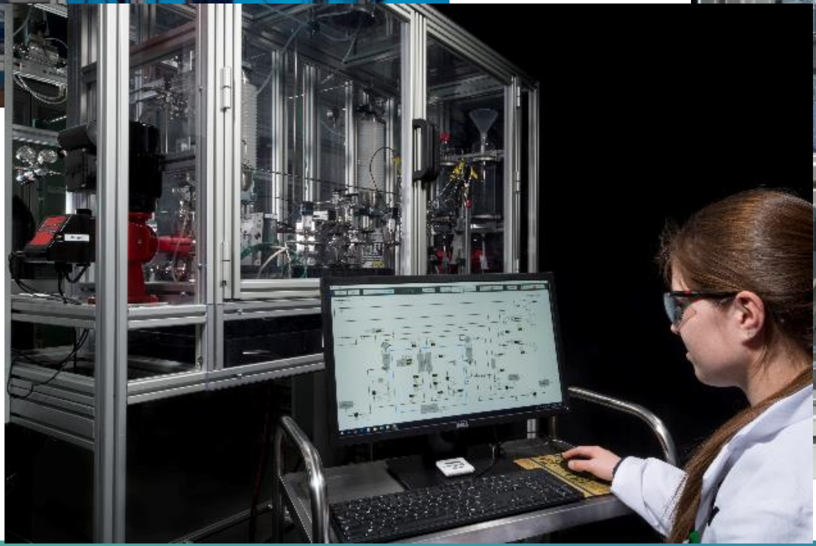


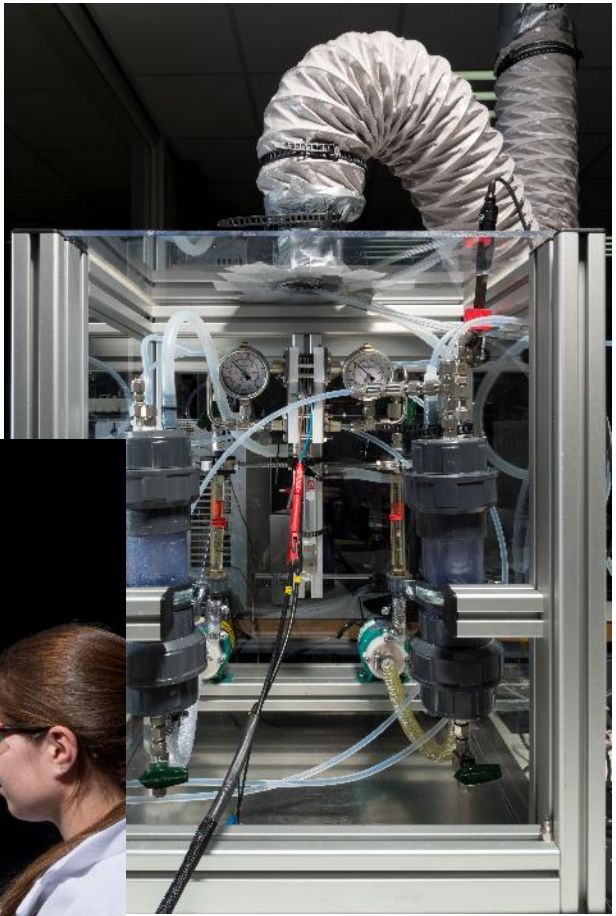
Lab-scale

Bench-scale

Pilot-scale

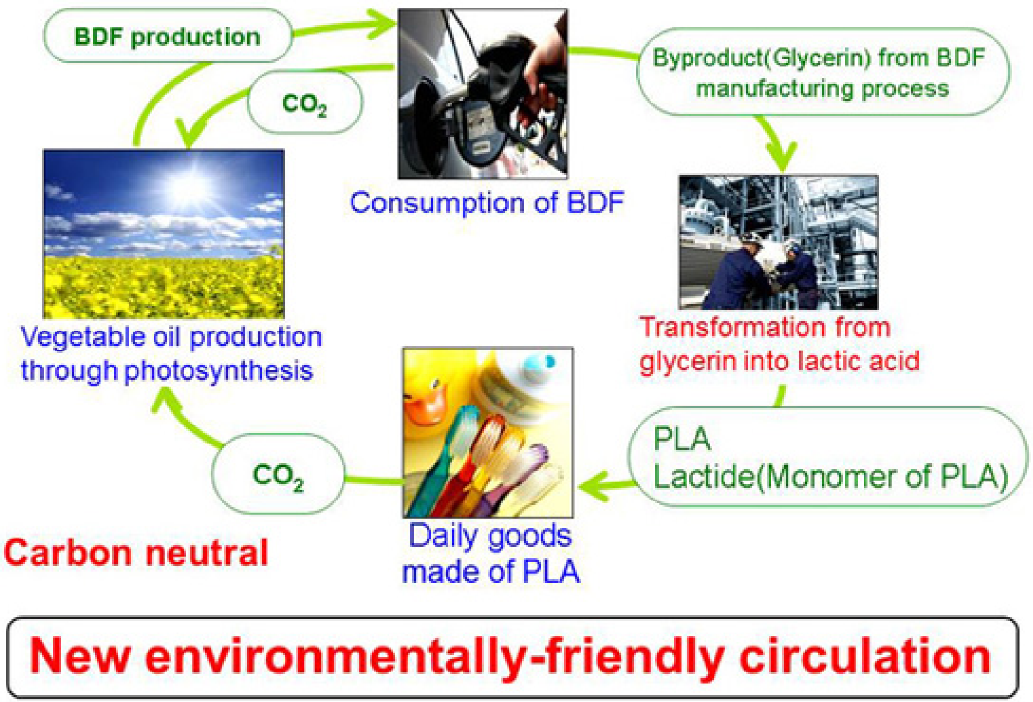
# Focus of TNO: upscaling of electrochemical production processes & TEA



# Lactic acid production: motivation & goals

**GOAL: demonstration of industrially feasible electrochemical continuous lactic acid production from a renewable feedstock**




Energy Procedia. Volume 56, 2014, Pages 195–200

- LA demand to increase 5-8% yearly, ~400kt/year
- **Renewable feedstock:** biobased glycerol derived 1,2-propanediol (PDO)
- Selective oxidation of alcohol groups is challenge.

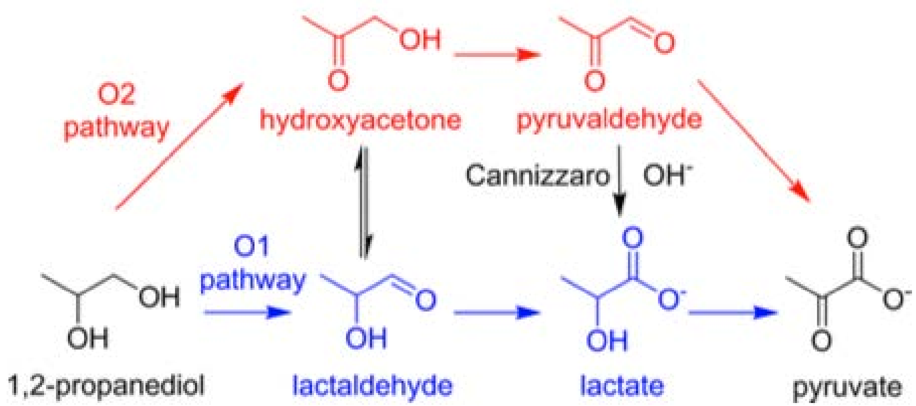
# Lactic acid production

- Fermentation (70-90% in 2009)
- Thermocatalytic oxidation on noble metals (Au, Pt, Pd & alloys)
- Electrochemical oxidation on noble metals (Pt, Au) in strong alkaline medium


**Electrochemical production:**

- No use of oxidants & minimal waste
- ~100% conversion
- Stable process
- Ambient conditions
- Control over reaction
- Low product concentration
- Stability of electrodes
- Current densities

# Direct electrolysis of lactic acid

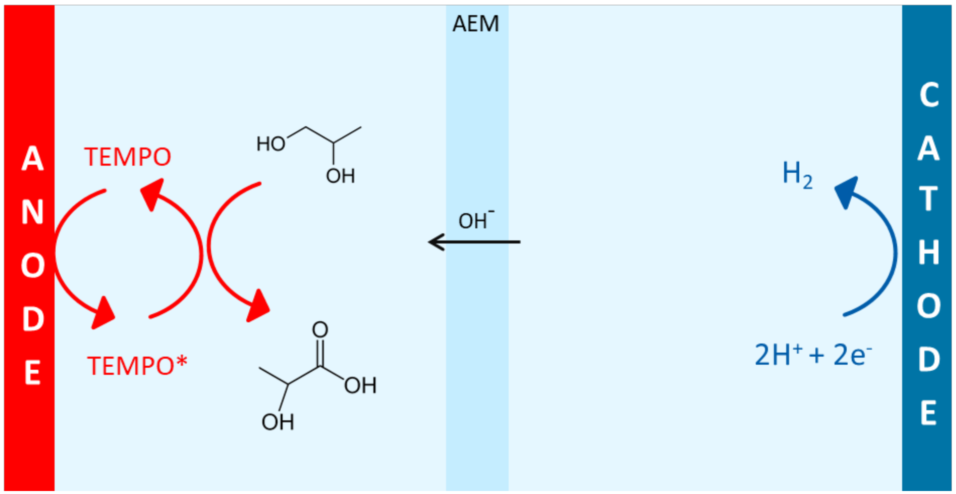


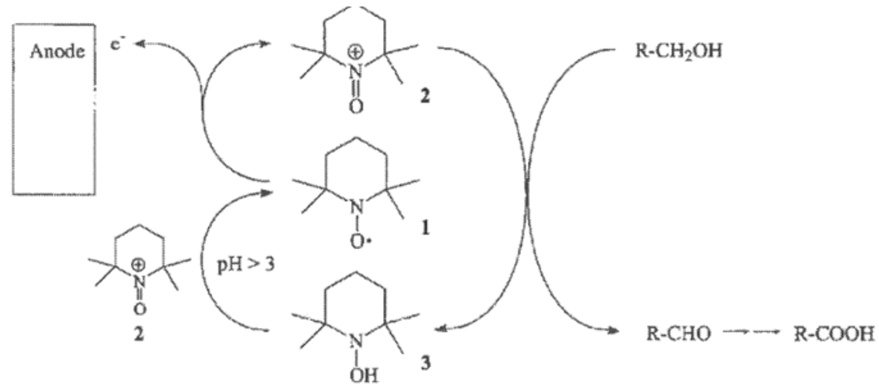

Chadderdon, ACS Catal. 2015, 5, 6926−6936

Screening of direct electrochemical oxidation on

1. pH<1
   - Pt — low current densities
   - $PbO_2$ — formic and acetic acids produced
2. pH>12
   - Pt — Selectivity 93% LA, 17% acetic acid (2M KOH, 50 $^0$C), low current efficiencies
   - Ni/NiOOH — formic and acetic acids produced

# Mediated lactic acid electrolysis (TNO patent)




Cathode: $2H^+ + 2e \rightarrow H_2$

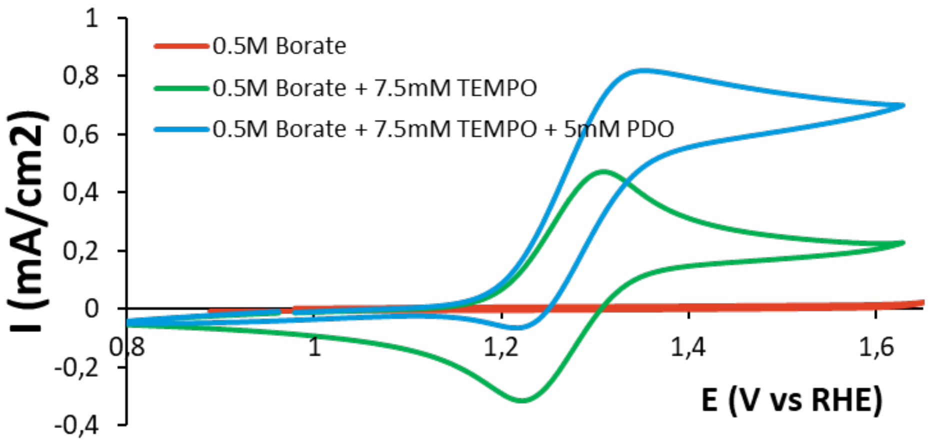
Anode: TEMPO - e $\rightarrow$ TEMPO*

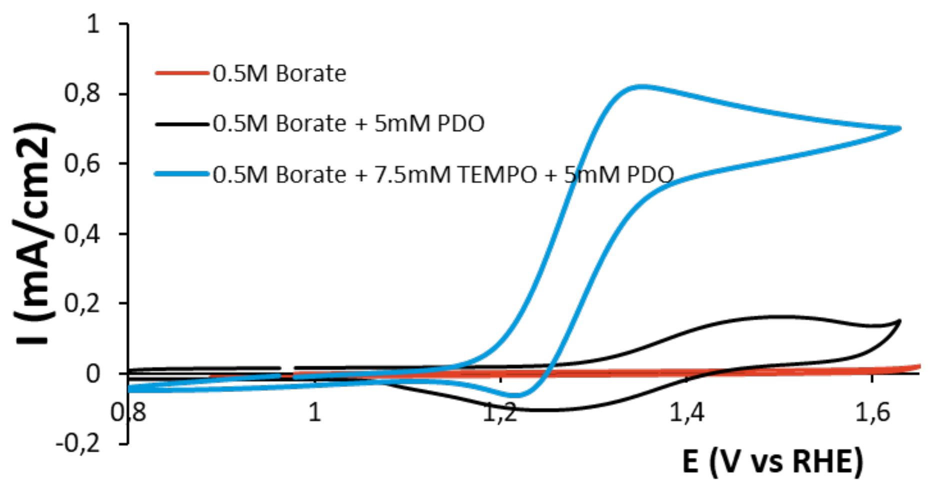
$C_3H_8O_2 - 4e \rightarrow CH_3CH(OH)COOH$

$CH_3CH(OH)COOH - 2e \rightarrow CH_3COCOOH$

Oxidation on Carbon based porous electrodes instead of noble metals!

# Cyclic voltammetry

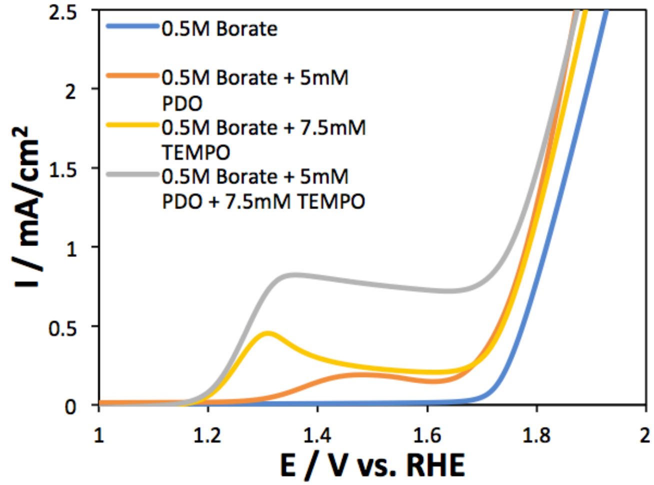


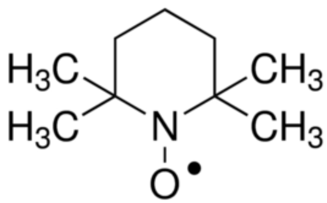



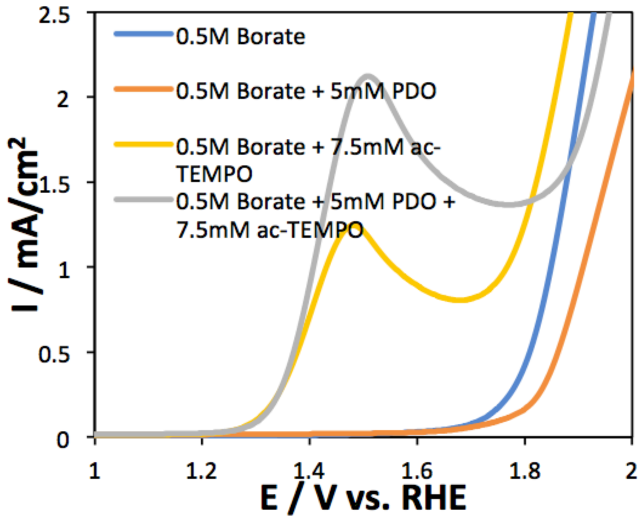

**Cyclic Voltammetry on graphite, pH 9**

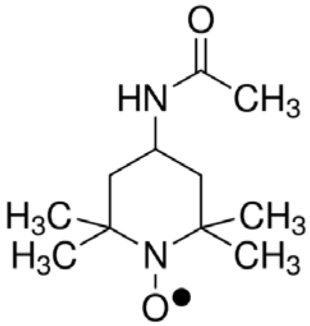
- Only borate: no oxidation
- Direct oxidation PDO:
  - Peak potential oxidation PDO: 1.48V
  - Peak potential reduction PDO: 1.26V
- Indirect oxidation PDO (TEMPO added):
  - Peak potential oxidation: 1.31V
  - Peak potential reduction: 1.22V

# TEMPO vs ACT



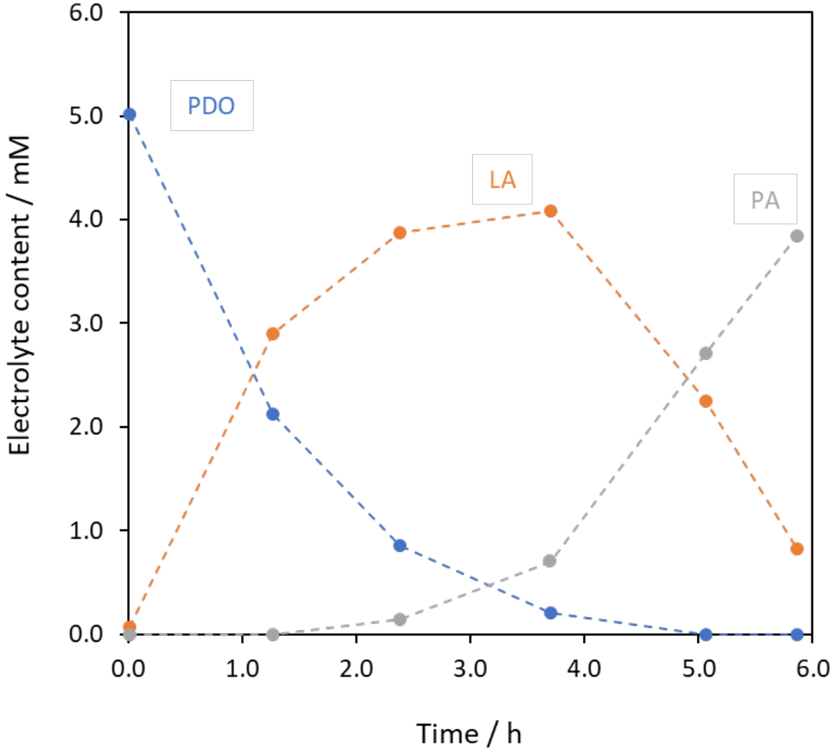



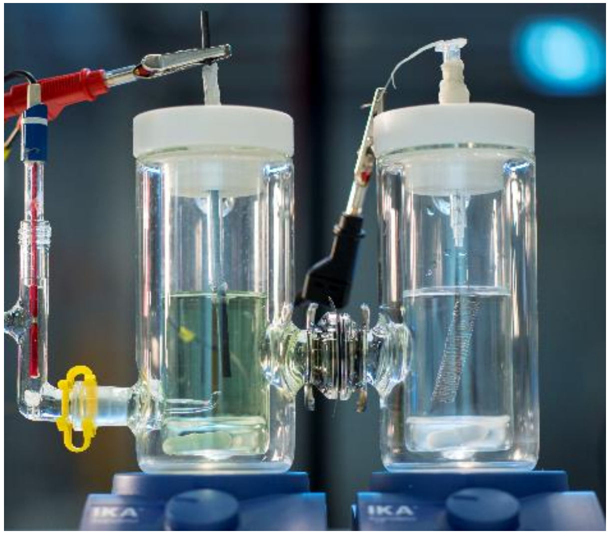




- TEMPO oxidation peak potential 1.34 V vs. RHE
- ACT oxidation peak potential 1.42 V vs. RHE
- Higher current densities with ACT
- ACT cheaper, good replacement

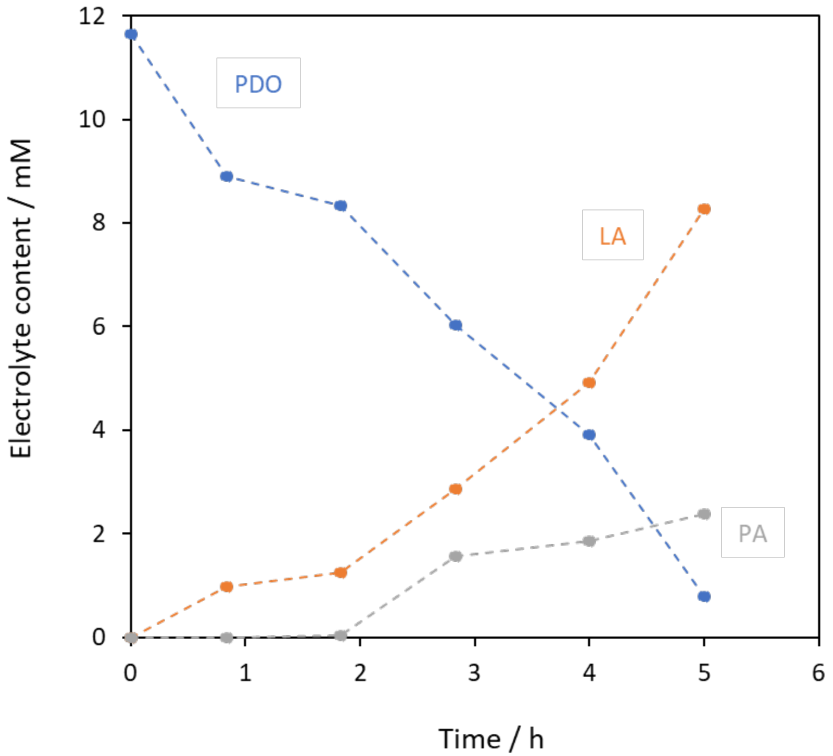
# Lactic acid electrolysis



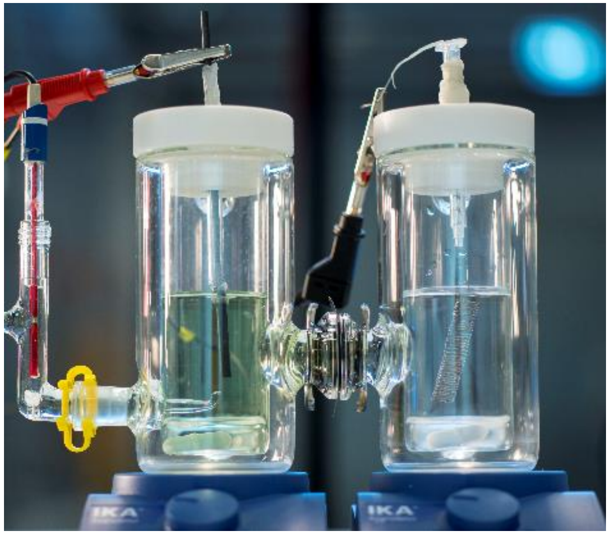

- Anode: carbon felt, ACT
- Anolyte: pH 10 buffer with 0.5 M $Na_2SO_4$
- RT
- Current density: 5-10 mA/cm2
- Current efficiency: 90% LA
- Yield LA: 80%



# Lactic acid electrolysis



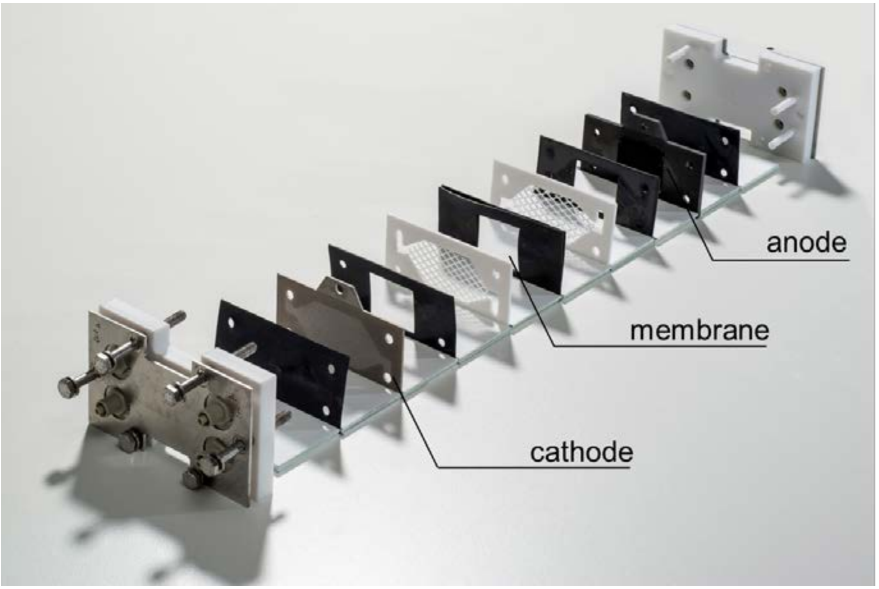

- Anode: carbon felt
- Anolyte: pH 10 buffer with 0.5 M $Na_2SO_4$
- 30 0C
- Current density: 30-40 mA/cm2
- Current efficiency: 70-80%
- Yield LA: 75%



# Upscaling ongoing

| | |
|---|---|
| • Current density | >100 mA/cm$^2$ |
| • Yield | >90% |
| • Current efficiency | >85% |
| • Cell voltage | <2.5V |
| • 3D electrodes | carbon felt |
| • Cheap electrolyte | $Na_2SO_4$, no buffer? |

- Reactor design: optimization of electrode utilization
- DSP & Electrolyte recycling

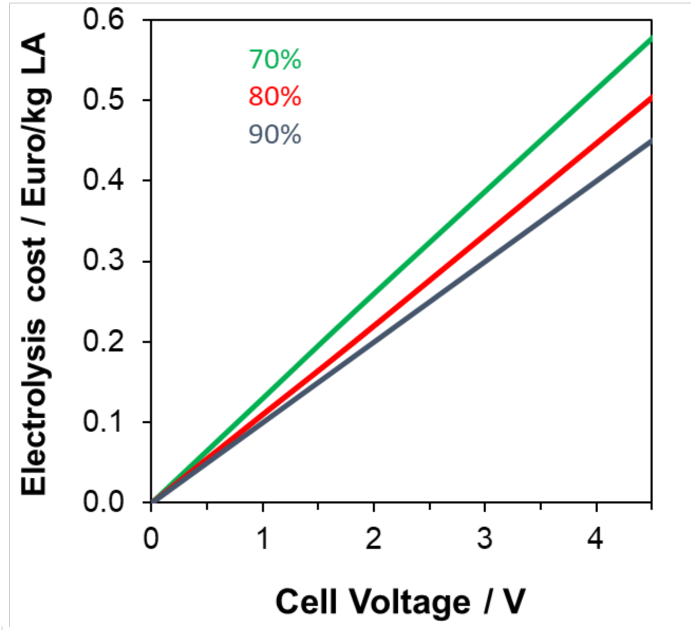


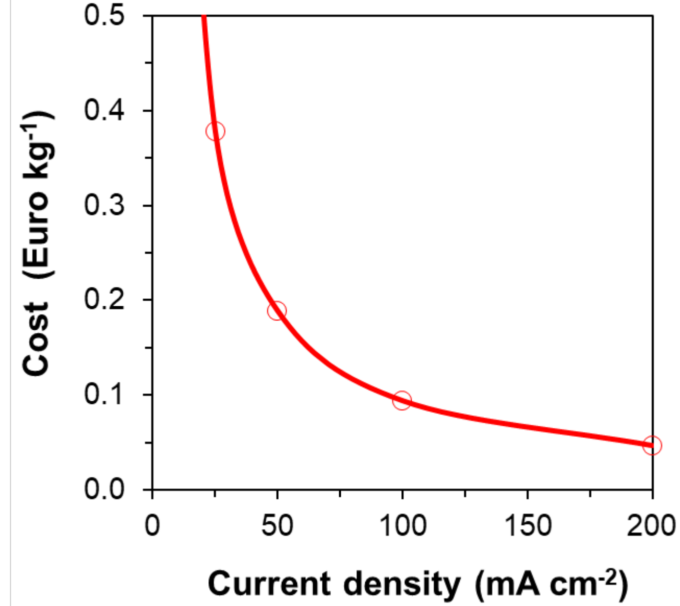
# Costs

- Total cost 300 Euro/tonne (without DSP)
- Lactic acid price 600-1000 Euro/tonne
- Price of pyruvic acid  5000 Euro/tonne (market?)

| Data used for OPEX calculation* | |
|---|---|
| Current efficiency | 70-90 % |
| Current density | 100 mA/cm2 |
| Reaction yield | 100 % |
| Electricity cost | 0.075 Euro/kWh |
| Base case cell volt. | 2.5 V |

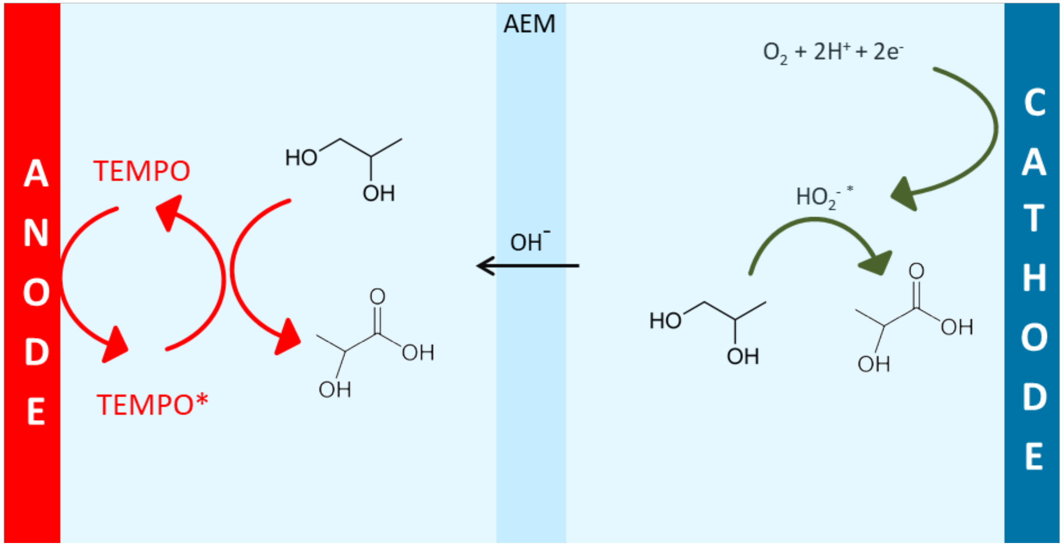
| Data used for CAPEX calculation* | |
|---|---|
| Current efficiency | 80 % |
| Current density | 100 mA/cm2 |
| Reaction yield | 100 % |
| Cost of anode | 200 Euro/m2 |
| Cost of cathode | 2000 Euro/m2 |
| Cost of membrane | 300 Euro/m2 |
| Cell costs | 500 Euro/m2 |
| Factor to other costs | 1 |

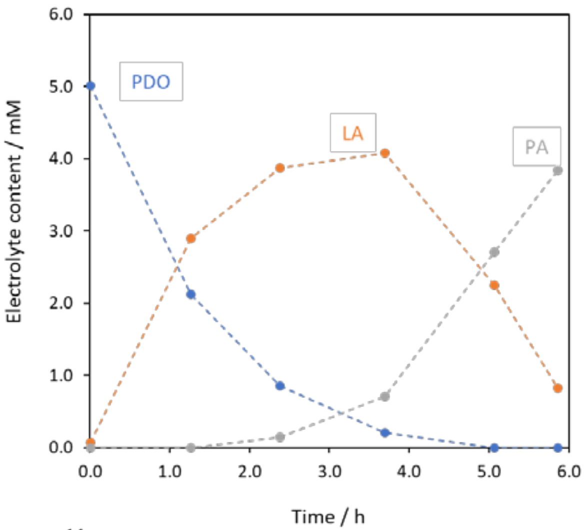


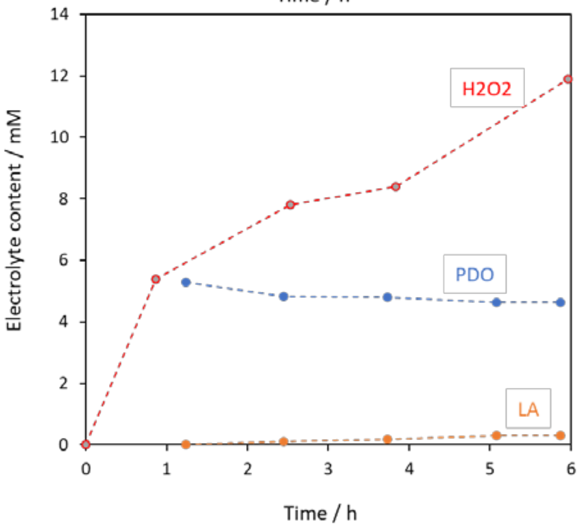



# Paired-electrolysis: proof-of-concept

- Production of lactic acid on both sides of the cell
- Homogenous catalyst required to catalyse peroxide mediated oxidation of PDO to LA
- Cathode: CE H2O2 71%, Yield LA 6%
- Anode: CE 75%, Yield LA 80%

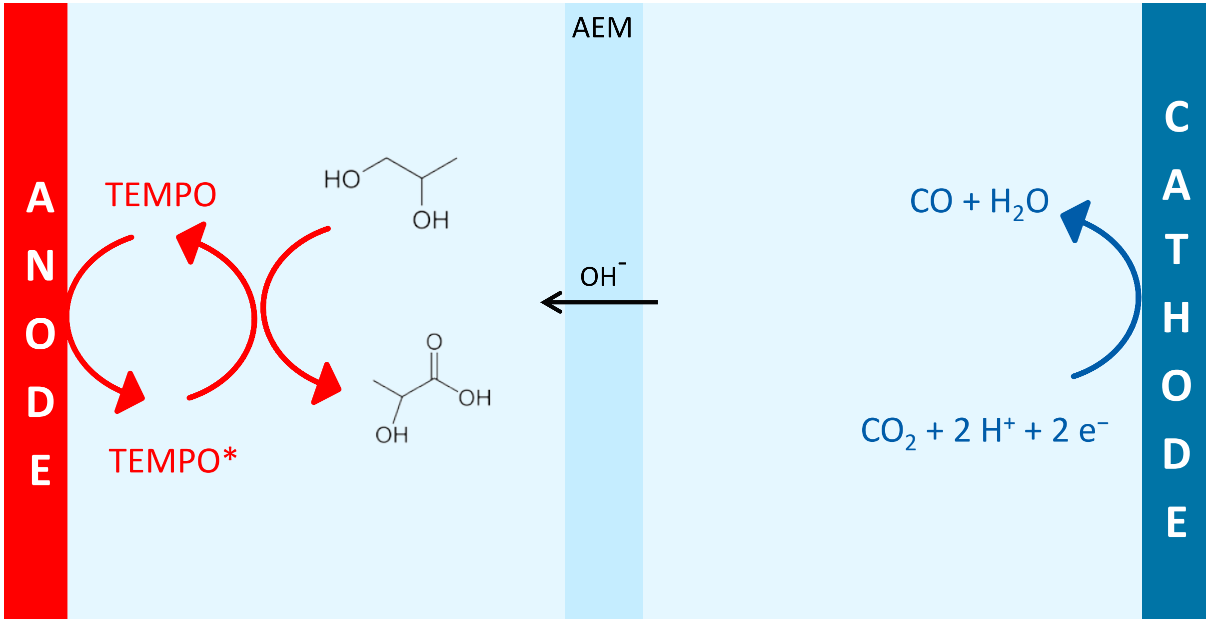


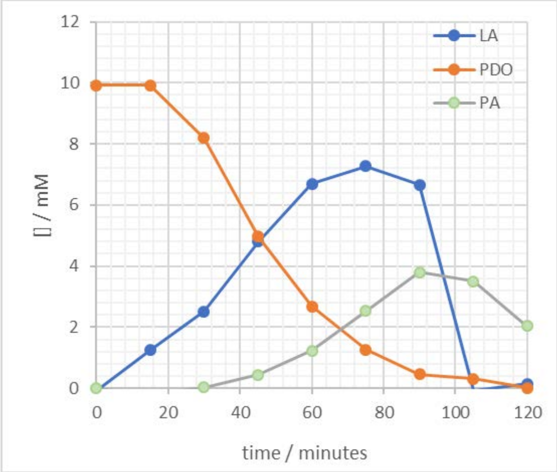



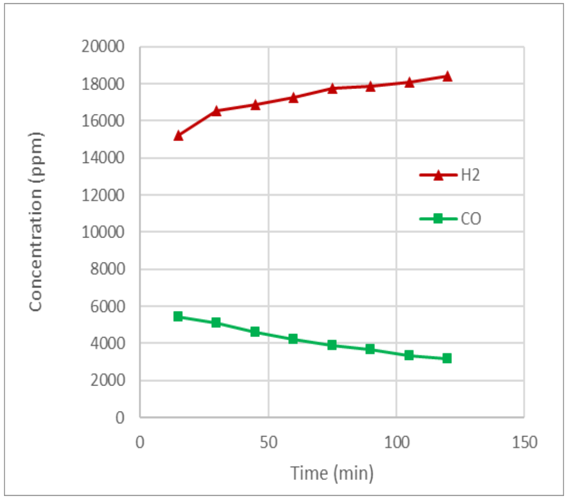



# Paired-electrolysis: proof-of-concept

- Production of lactic acid with co-production of CO
- **Pt anode replaced with graphite & cell voltage lowered -> halving CO electrolysis costs**
- CO current efficiency to be optimized
- Process upscaling strategy



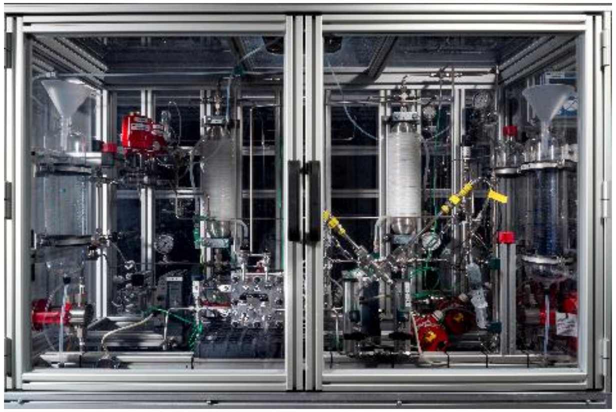



# Summary

- Electrochemical lactic acid produced in aquoues electrolytes and ambient conditions with high current efficiencies, 90%, and yields, 80%
- Electrolysis is cost efficient (~300 Euro/tonne), DSP research ongoing
- Paired electrolysis in order to improve business case. Proof-of concept for:
  - Lactic acid production on both electrodes
  - CO co-production on cathode

- Next step, reaction and process optimization and up-scaling

# Thank you for your attention!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